Pspice Simulation of NL-Transmission Line A/D Conversion

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Abstract

Nonlinear transmission lines (NLTL) that consist of coplanar waveguide periodically loaded with resonant tunnel diode are capable of shaping signal waveforms during transmission. Such system is the basis of very interesting microwave signal generation circuits and it has a lot of applications in electronics. Pspice is used to model analog to digital converter by generating short electrical pulses on a nonlinear transmission line. Nonlinear transmission line is realized as electrical lattice with *N* electrical cells coupled by inductor and resistor in series. Each cell consists of a resonant tunnel diode in parallel with both resistor and capacitor. Attenuation represented by the resistor is cancelled by nonlinear effect. This cancellation produces the desired effect.

Keywords

Nonlinera Transmission Line; Resonant Tunneling Diode; Signal Reshaping; Analog to Digital Converter

Introduction

The high speed performance of most digital systems is limited by distributed transmission line effects of packaging and interconnects, instead of switching speed of semiconductor devices. In many cases, the quest of higher performance is centering on layout and topological considerations. System performance can be improved by studying transmission line effects (Winklestein *et al*., 1991).

The nonlinear transmission line (NLTL) has three fundamental and quantifiable characteristics just as any nonideal transmission line. These are nonlinearity, dispersion, and dissipation. Along with some other characteristics (e.g. impedance, length, etc.), they define a transmission line's behavior with arbitrary simulation. What distinguishes one class of line from another is the degree to which these characteristics occur and interact. Resonant tunneling diodes have demonstrated maximum frequency of oscillation as high as 1.2 THz. Having the highest frequency among active devices, RTD's have been employed in oscillator, mixer, and switching applications (Hoffmann, 1987; Liu and Coon, 1987; Özbay *et al*., 1993).

NLTLs consisting of coplanar waveguide (CPW) periodically loaded with resonant tunneling diodes (RTD) provide nonlinearity due to the N-shaped of current-voltage characteristic of the RTD, dispersion due to the periodicity, and dissipation due to the finite conductivity of the CPW conductor and parallel resistance of the diodes (Brown *et al*., 1991).

These NLTL are capable of generating picosecond electrical pulses (Juger, 1985). An important related application is pulse sharpening for the more traditional non-return-to-zero (NRZ) data transmission in digital circuits by improving the rise and fall times of the pulses. Improving the transitions by shrinking the rise and fall times of pulses can be useful in other applications, such as high speed sampling and timing systems (Afshari and Hajimiri, 2005).

It has shown by previous studies that pulse reshaping is closely related to the N-shaped current-voltage characteristic of RTD (Vorontsov, 1964). Essimbi and Juger (2010) have performed a study of generating short electrical pulses using a schottky transmission line periodically loaded with RTD. They have been able to break down single wide pulse into multiple pulses.

This work is focused on the properties of microwave transmission lines periodically loaded by RTD. Next section presents the model of NLTL. Then, Pspice simulation results and their significance are presented, followed by conclusion in the last section.

Model Description

The equivalent circuit of the nonlinear transmission line

(NLTL) used in our simulation is represented in FIG. 1. The equivalent circuit consists of N repeated cells of resonant tunneling diode (RTD) in parallel with capacitor (c) and parallel resistor (Rp). Each cell connected in series with inductor (l) and resistor (R). Using Kirchhoff laws we can write the equations which govern the processes of the nonlinear waves in this equivalent circuit.

$$c\frac{dV_n}{dt} = I_n - I_{n+1} - J_n - \frac{V_n}{R_p} \qquad (1)$$

$$L\frac{dI_n}{dt} = V_{n-1} - V_n - RI_n \qquad (2)$$

where V_n and I_n are respectively the voltage at the n^{th} node and current entering the n^{th} node, and J_n is the current through the RTD defined by

$$J_n = BV_n(V_n - U_1)(V_n - U_2) \qquad (3)$$

where U_1 and U_2 are constants, and B is the factor which is determined by the slope at V=0. Equation (3) shows that the RTD current-voltage characteristic obeys the cubic relation.

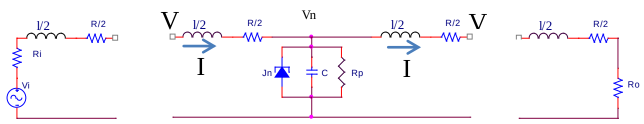


FIG. 1 EQUIVALENT CIRCUIT OF RTD-NLTL

The RTD current-voltage characteristic curve, equation (3), for different values of U_1 and U_2 are plotted in FIG. 2. FIG. 2a shows the RTD characteristic curve at U1 = 0.1V and U_2 = 0.2V. In this case, the area S_1 that is above the zero current line equal the area S_2 under the zero current line. While FIG. 2b represents the characteristic curve at U_1 = 0.1 V and U_2 = 0.3V. Here $S_1 < S_2$. The RTD characteristic curve at U_1 = 0.2V and U_2 = 0.3V is plotted in FIG 2c where $S_1 > S_2$.

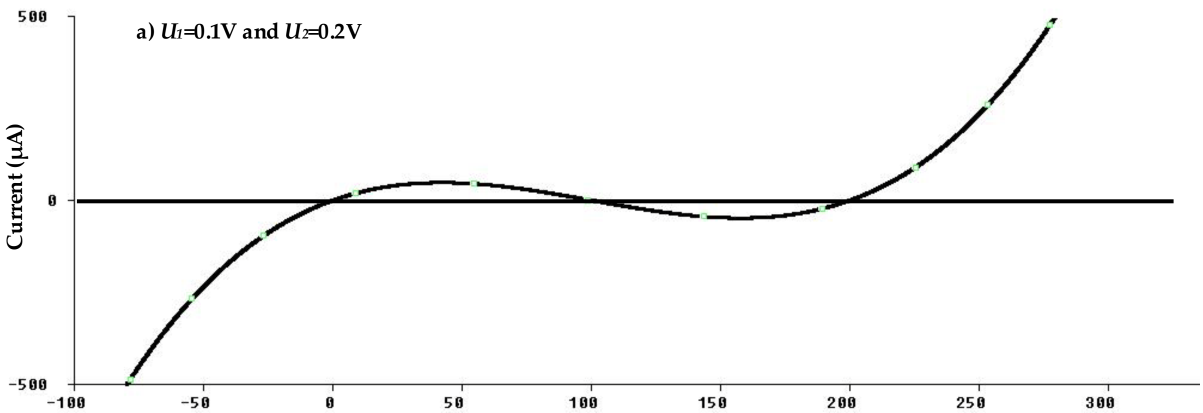
Circuit Parameters and Numerical Results

The experimental electric circuit is composed of N=80 elements, where the values of the parameters are as follows: R=0.25Ω, c =53.1fF, l=37.3pH, and R_p=10KΩ. The input resistor R_I =50 Ω is introduced at the input port of the circuit to an input voltage and the output is set free. Equation (1) and (2) are solved numerically using Pspice simulation program.

The input voltage is defined to be a sinusoidal signal with amplitude 0.5V and frequency 2GHz. The output at N=30, 40, and 50 for U_1=0.1V and U_2=0.2V, S_1=S_2, is shown in FIG. 3. The output signal has a kink and antikink structure with constant pulse width. Repeating the measurement with U_1=0.1V and U_2=0.3V where S_1< S_2, we get FIG. 4. In this case, we notice that the pulse suffers from dispersion where the pulse width widens as it propagates. However, when U_1=0.2V and U_2=0.3V where S_1> S_2, the pulse will propagate while its width decrease as exhibited in FIG. 5.

Conclusion

Nonlinear transmission lines (NLTL) modeled as N electrical cells consisting of RTD in parallel with capacitor and resistor coupled by inductor and resistor in series are capable of shaping signal waveform during transmission. Such system is the basis of very interesting microwave signal generation circuits and it has a lot of digital applications. Pspice is used to model analog to digital converter by generating short electrical pulses on a nonlinear transmission line. Attenuation represented by the resistor is cancelled by nonlinear effect. This cancellation producing kink and antiknik pulses which have a fast rise time is an indication of the usefulness of the system in converting analog to digital signal.



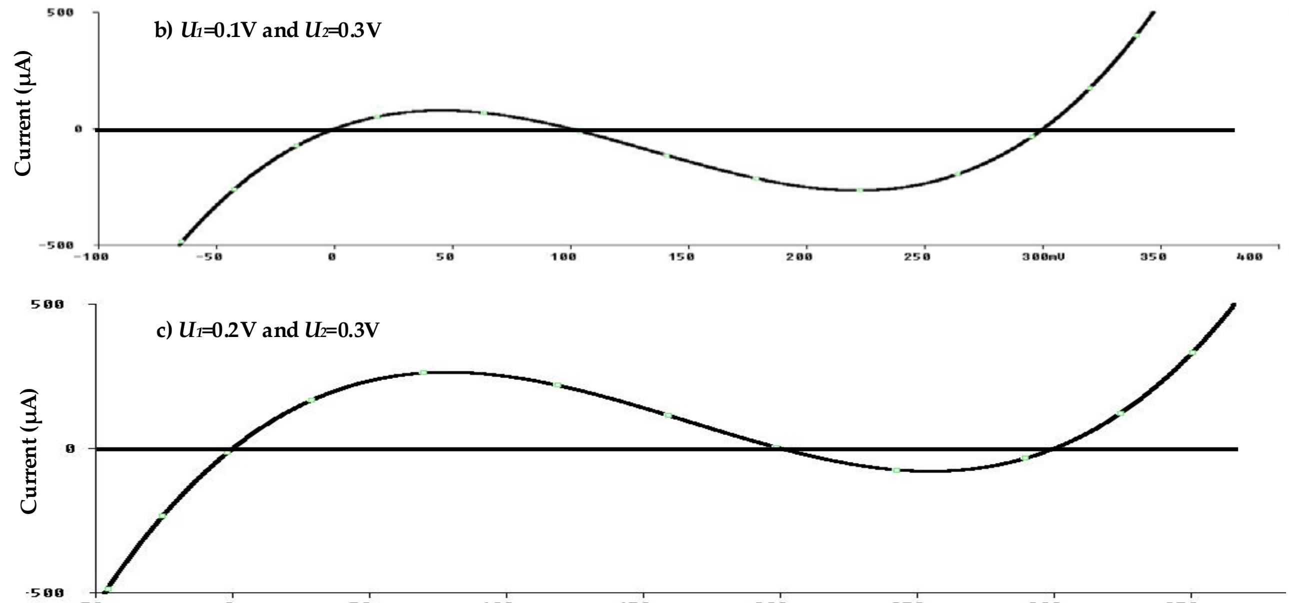


FIG. 2 The CHARACTERISTIC CURVE of THE RTD at DIFFERENT VALUES of U_1 and U_2 as INDICATED in the FIGURES

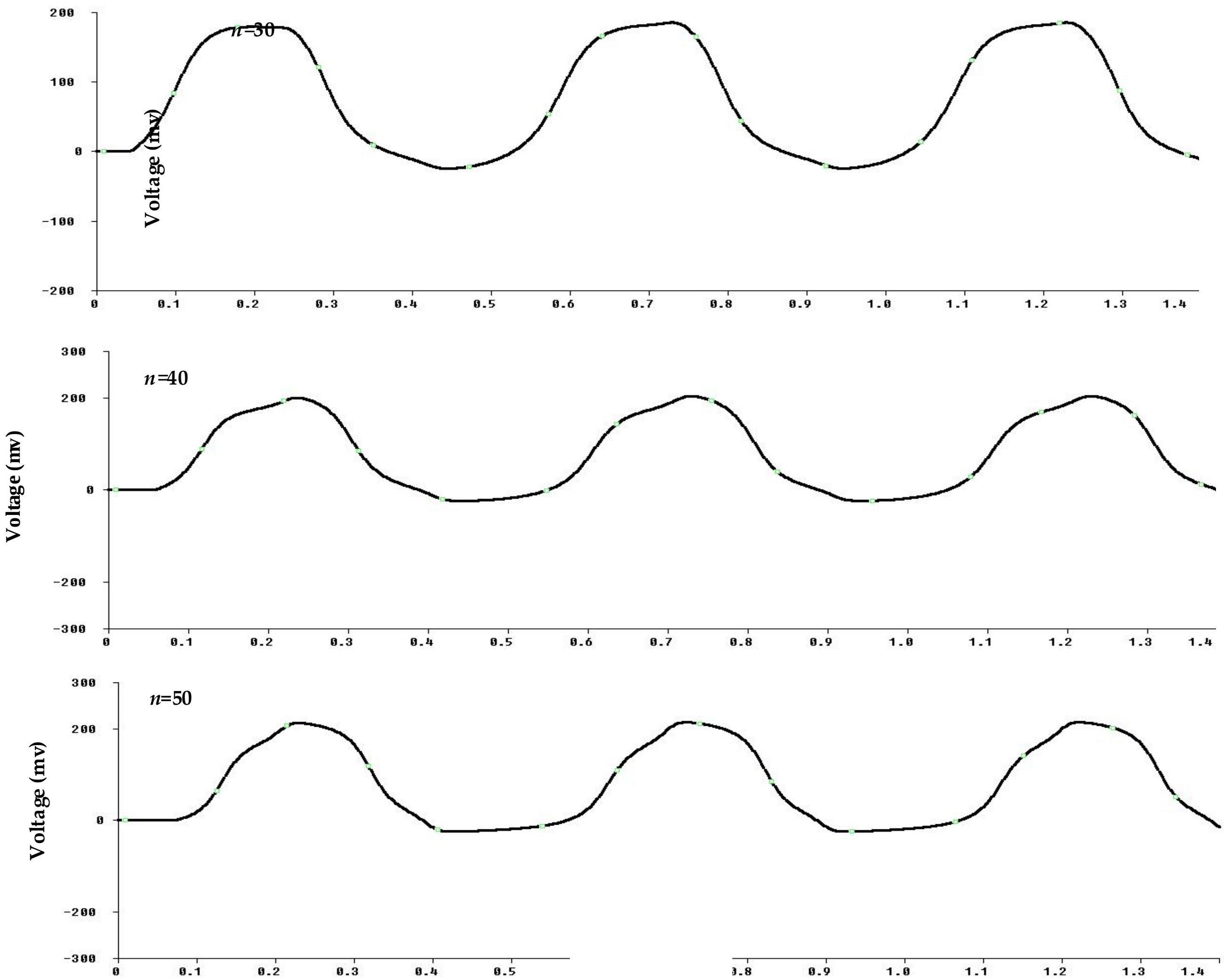


FIG. 3 PULSE PROFILE VERSUS NORMALIZED TIME at n=30, 40, 50, U_1=0.1 and U_2=0.2.

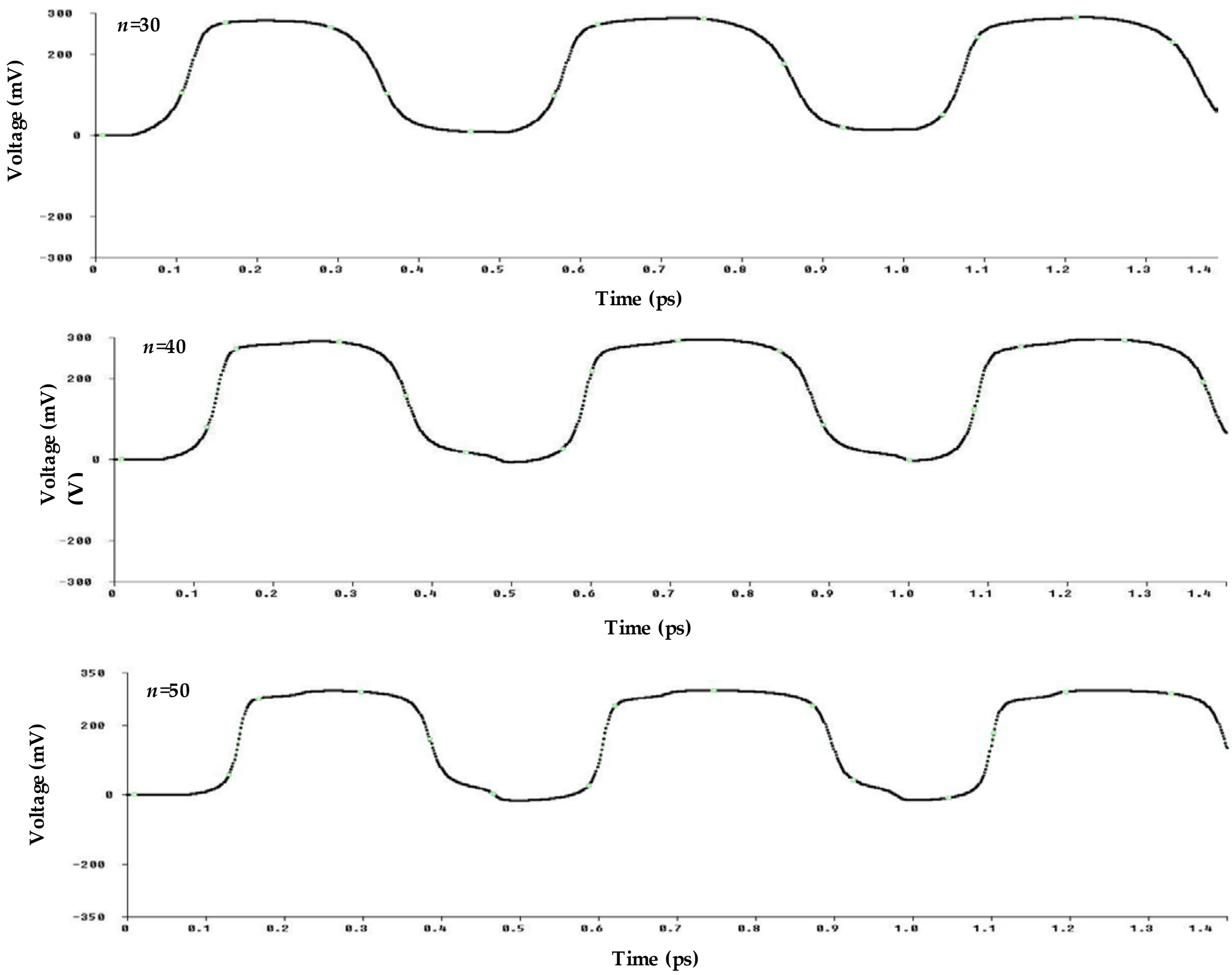
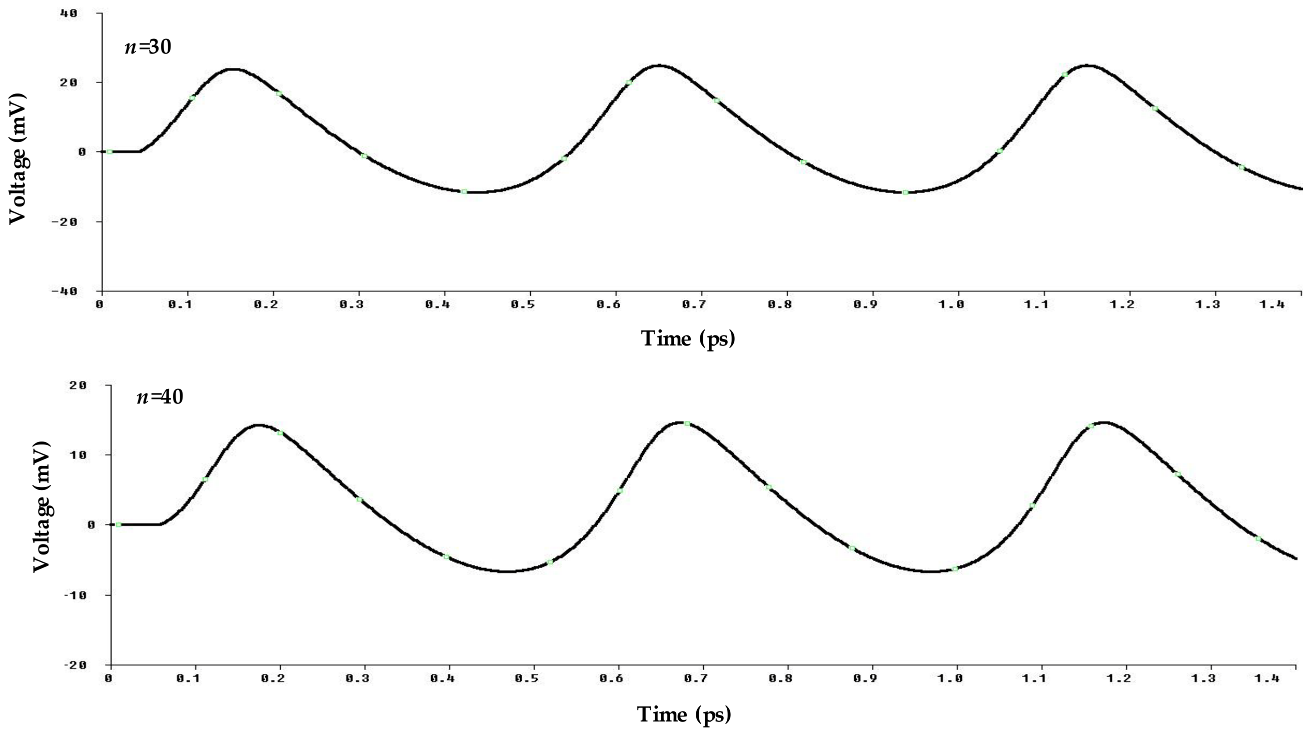


FIG. 4 PULSE PROFILE VERSUS NORMALIZED TIME at n=30, 40, 50, U_1=0.1 and U_2=0.3.



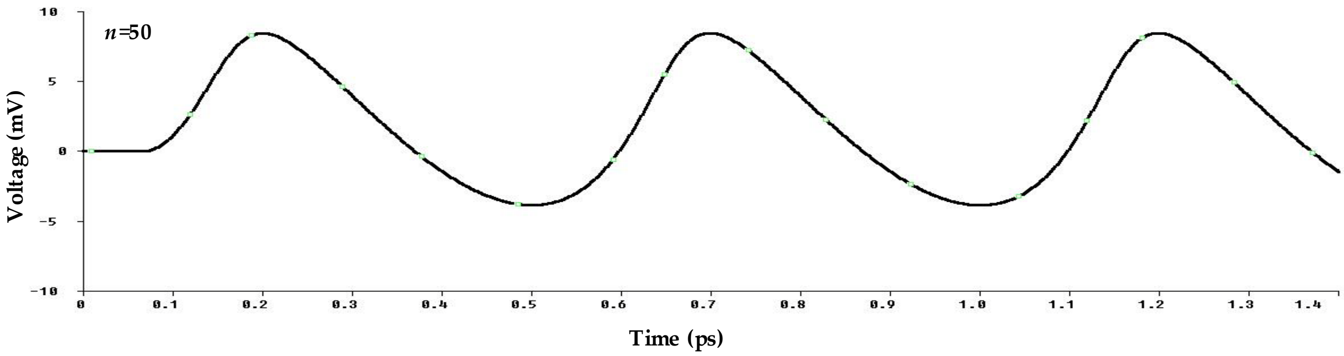


FIG. 5 PULSE PROFILE VERSUS NORMALIZED TIME at n=30, 40, 50, U_1=0.2 and U_2=0.3.

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